

Annual Report for Continuing Studies of Sea Urchins Settlement in Southern and  
Northern California (CDF&G P9970009)

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## SUMMARY

The patterns of settlement of red (*Strongylocentrotus franciscanus*) and purple (*S. purpuratus*) sea urchins may have important impacts on the commercial fishery. We have monitored weekly sea urchin settlement at multiple sites in southern and northern California since February 1990. The study is now in its twelfth year, encompasses 11 settlement seasons and will include an additional season in 2002. Significant findings to date, include:

- (1) Settlement of both species of sea urchins is generally seasonal and discontinuous. The settlement “season” generally occurs between January and August, however, the timing of abrupt peaks in settlement vary from year to year.
- (2) Settlement peaks tend to occur within the same quarters of a given year over large geographical areas. Despite this, there are site-to-site differences in settlement and differences in the exact timing of settlement within a quarter.
- (3) Marked differences in settlement patterns occur between northern and southern California. Settlement is generally greater and more frequent in the Southern California Bight (the stretch of coastline between Point Conception and the Mexican border) than in northern California, and the interannual variation in settlement is greater in northern California.
- (4) Settlement responds to the changes in large-scale oceanographic conditions associated with El Niños in both northern and southern California, but these responses differ markedly between regions. In northern California large settlement events occurred during the relaxation of upwelling associated with El Niño conditions in 1992, 1993, 1997 and 1998. By contrast, settlement in southern California was lower during the El Niños and increased following the end of the El Niño conditions.

## INTRODUCTION

Red and purple sea urchins represent a large class of marine organisms with sedentary adults and larvae capable of long-distance dispersal. This style of life history results in a set of local spatially-structured populations that are interconnected by larval dispersal. Although red and purple urchins have been known to move tens or hundreds of meters during episodes of heavy grazing, they probably move less than a kilometer over a lifetime and almost certainly spend most of their lives on a particular reef or in a particular kelp forest. By contrast, the larval stages of both species remain in the plankton for at least 5 weeks before settling into the benthos (R. Strathman 1978, Cameron & Schroeter 1980, Leahy 1986, M. Strathman 1987, Rowley 1989) during which time they may be carried hundreds or perhaps thousands of kilometers from the parent populations.

Understanding the meta-population structure of red and purple sea urchins would be extremely useful for managing the commercial fisheries for both species. Ideally, one would like to know where the larvae come from and where they go. This is a difficult problem which we have approached in three ways. First, we monitored weekly settlement of red and purple urchins multiple sites encompassing a significant portion of the geographical range of both species for more than a decade. Second, we sought physical oceanographic data with which to correlate settlement patterns. The length of our experiment has allowed us to encompass a variety of oceanographic conditions, including two major El Niño/La Niña cycles. Finally, we have maintained a library of all settlers for genetic analysis in hopes of finding markers that would tie the larvae to particular locations. These analyses are currently being conducted in collaborative work with Dr. Ronald Burton at Scripps Institution of Oceanography.

Our previous work through mid-1993 (Ebert et al. 1994) showed that: (1) purple urchins generally settle in larger numbers than do red urchins; (2) settlement of both species varies greatly from place to place, but settlement is generally greater and perhaps more frequent in the Southern California Bight than in northern California. However when settlement occurred in the north in 1992, it was similar to that in southern California; (3) within northern or southern California there were some locations where settlement was

predictably more frequent and intense than at other sites; and (4) temporal and spatial patterns of settlement of red and purple sea urchins correlate with general oceanographic processes along the California coasts, but settlement patterns in northern and southern California differed significantly. There was little settlement of red or purple urchins in northern California in 1990 and 1991, but during the next two years, large numbers of purple urchin settled and the settlement of red urchins was also higher than in the preceding years. This change coincided with an El Niño event that started late in 1991 and continued through the 1993 settlement season (Hayward 1994). Settlement patterns in southern California contrasted sharply, showing little differences for some sites from 1990 through 1993, and an obverse pattern for other sites. The work we summarize here adds another 8 years of data and encompasses another significant El Niño event, giving an opportunity to see whether correlation between patterns of sea urchin settlement and large-scale oceanographic processes tends to be a consistent one.

Finally, aside from shedding light on metapopulation structure, the long-term, geographically extensive settlement record affords the opportunity to test for temporal trends in settlement rates that might signal a change in larval production by the metapopulation. Such information provides an important fishery independent measure of the health of urchin stocks and could provide a signal for recruitment over fishing.

## METHODS

**Settlement collectors.** Accurately estimating the supply of newly settled sea urchins requires one to either estimate or eliminate post-settlement mortality. We have followed the latter strategy by using artificial settlement surfaces suspended above the sea floor, which are collected on a weekly or bi-weekly schedule. Although our methods do not eliminate post-settlement mortality, by reducing the exposure of newly settled sea urchins to potential predators and shortening the time over which any other sort of mortality might act, they tend to reduce the confounding effects of post-settlement mortality on our estimates of settlement supply Miller and Emlet (1997).

A variety of artificial settling surfaces have been used to monitor sea urchin settlement, including a variety of rigid plastic designs (Dept. of Mariculture Hokkaido 1984; also see

Tegner 1989), PVC pipes with plastic light diffusers inserted (Harrold et al. 1991), fiberglass roofing material, artificial grass (Astroturf<sup>TM</sup>), and wooden scrub brushes with nylon bristles (Ebert et al. 1991).

Data for the work presented here were collected from wooden scrub brushes with nylon bristles (#0115, National Brush Company, Aurora, IL, USA), based on preliminary tests on three types of brushes (Ebert unpubl.). The brush has a 6 x 9 cm base with 48 bundles of 2.5 cm long nylon bristles. Brushes offer an inexpensive source of artificial substrates with identical physical characteristics.

Brushes were attached to nylon lines, one meter above the sea floor, which were suspended from piers or overhanging rock ledges. Two to four lines were deployed at each site. Each line held from 2 to 4 pairs of brushes, giving a total of 8 to 32 brushes per site. On each line, the bottom pair of brushes was attached 1 meter above the sea floor, and subsequent pairs were spaced 20 cm above the lower set. A groove was cut into the back of each brush so that when two brushes were placed back-to-back the nylon line fit snugly into the space created. Each brush pair was held together with nylon cable ties and the line was knotted to prevent the brushes from moving up or down along it (Fig. 1). A 4 to 5 kg weight was attached to the bottom of each line.

Brushes were collected at one- to two-week intervals and replaced with brushes that had been collected during the previous collection period and had been rinsed in fresh water. Following collection, the brushes were placed in plastic bags and transported to the laboratory.

Two methods were used to remove newly settled invertebrates from the brushes. At laboratory locations lacking a flowing sea water system (San Diego and Fort Bragg) each brush was placed brushed bristle-down in a sonic cleaner for 3 to 5 minutes. During sonication, the bristles were rubbed by hand to aid in freeing animals from deep inside the bristles. At the UCSB marine laboratory, which has a flowing sea water system, the bristles were vigorously scrubbed by hand and periodically rinsed with a high-pressure stream of seawater for 3 to 5 minutes. Comparison of the two methods showed no differences in the rate of recovery of newly settled urchins.

After sonication or seawater rinsing was completed, the water was poured through a 0.436 mm mesh plankton netting, which was sufficiently small to retain newly settled sea urchins. The material retained on the netting was sorted under a dissection microscopy to large taxonomic categories and then preserved in 70% ethyl alcohol for later identification to species. Identification of newly settled sea urchins was based on the presence of dorsal pedicellaria and pigmentation. Purple urchins (*Strongylocentrotus purpuratus*) lack dorsal pedicellaria, while red urchins (*Strongylocentrotus franciscanus*) have from 1 to 3 (Rowley 1989). There is another sea urchin species in southern California, *Lytechinus anamesus*(= *pictus*), that also has dorsal pedicellaria, however, laboratory rearing of both species showed that it has less pigmentation than *S. franciscanus* (Schroeter, Ebert, and Dixon. unpubl.).

**Sites and sampling schedule.** Nine sites ranging from northern to southern California were selected between 1990 and 1992 (Fig. 2). Site selection was based on accessibility under most weather conditions and the availability of technicians to tend the collectors. In northern California, collectors were deployed in 1990: (1) off a rock overhang from shore at Point Cabrillo 24 km south of Fort Bragg, 2) off a rock overhang from shore at Westport, 44 km to the north, (3) from a pier at Arena Cove south of Point Arena and 96 km south of Point Cabrillo. In southern California collectors were deployed in 1990: (4) from Ellwood Pier, 96 km south east of Point Conception, (5) from Stearn's Wharf, just east of Santa Barbara Harbor and 147 km southeast from Point Conception; (6) from Scripps Institution of Oceanography Pier in La Jolla, and (7) from the Ocean Beach Pier in San Diego. In 1991, collectors were deployed at (8) the Gaviota Pier, 48 km southeast of Point Conception, and in 1992 at (9) the Landing Cove Pier on southeast Anacapa Island.

Settlement, or 'weekly recruitment' was monitored for different lengths of time at the different sites. Westport, Point Cabrillo, Ellwood Pier, and Ocean beach Pier were monitored from February/March 1990 through September 2001. Collectors were monitored at the Point Arena Pier from March 1990 through April 1991 and then again from May 1995 through September 2001. The Landing Cove Pier on Anacapa Island

was monitored from May 1992 through October 1999. Some gaps occur in the data due to vandalism or severe storm events.

**Analysis.** Analyses consisted of (1) plots of weekly and quarterly settlement of both red and purple sea urchins. In all plots, data were standardized to represent number of settlers per brush per week; (2) analyses of geographical coherence among sites over time; (3) Analyses of variance to compare differences in temporal trends of settlement among geographical regions and species; and (4) Examination of possible correlations between large scale oceanographic events (e.g. El Niños and La Niñas) and settlement time series.

Large-scale geographical coherence was examined by comparing plots of average yearly settlement rates from northern and southern California and conducting repeated measures analysis of variance to determine whether settlement rates showed similar patterns over the 12 year time series in the current study.

## RESULTS

Settlement of both species displayed patterns of strong seasonal and inter-annual variability in both northern and southern California that (Figs. 3-5).

Total annual settlement varied by species, year, and location (Figs 3-5; Table 1). In general, annual settlement of purple sea urchins was much higher than that of red urchins (Table 1). Variability across years was similar for the two species in southern California, but was higher in northern compared to southern California for red urchins (Table 1; Fig. 6).

Plots of regional mean annual settlement rates over time along with repeated measures analysis of variance indicates the presence of an interaction between the effects of region and year for both species (Tables 2 and 3). The source of the year and region x year effects are apparent when one examines the mean yearly settlement by region.

Settlement was higher in northern California for both species during the El Niño years of

1992/3 and 1998 than in the preceding or following years, while the obverse pattern occurred in southern California (Figs. 7 & 8).

Finally, there was no evidence of a linear temporal trend in settlement rates in northern or southern California for either red or purple urchins (Figure 7 & 8).

## **DISCUSSION**

As in our earlier work (Ebert et al. 1994), the present study finds consistent differences in settlement patterns between northern and southern California, and a similar correlation between large-scale oceanographic processes and settlement patterns. Weekly time plots of settlement (Figs. 3-5) show coherence within and differences between geographic regions. These patterns are borne out by the repeated measures analyses (Figs. 7 & 8; Tables 2 and 3), which shows no overall average differences in either purple or red urchin settlement between northern and southern California, but peaks and valleys of settlement in both regions which are coherent within but not between regions. This non-alignment of peaks and valleys is due to different regional responses to El Niño / La Niña oceanographic conditions. However, details for these mechanism are not clear at present. In southern California, settlement tends to be lower during El Niño years than in the preceding or following years, while in northern California the opposite pattern occurs. The mechanism for higher settlement during El Niño conditions in northern California is consistent with reduced offshore and increased onshore transport caused by the reduced southeast transport by the California Current (Chelton 1981, Simpson 1984a, b). Lower settlement during years proceeding or following El Niño conditions would coincide greater southeast transport of the California Current and resulting greater incidence of upwelling and offshore transport. If we assume that our settlement measures correlate with the supply of larvae to the shore, our observations in northern California are consistent with those of Roughgarden et al. (1988) who showed that barnacle larvae tended to be found farther offshore during periods of strong versus weak upwelling. Evidence for this mechanism also comes from the comparison of temperature and settlement data near Fort Bragg. Settlement peaks occurred only when temporal patterns of temperature change were either flat or rising, indicating either relaxation of upwelling

or shoreward flow of surface waters. The lower settlement of red and purple urchins in southern California during El Niño events is not explained by the above model. It is nevertheless a consistent pattern and agrees with an earlier 8-year study at False Point near San Diego, which found reduced annual recruitment of purple urchins during years when the thermocline was depressed, Ebert (1983).

The records of weekly settlement for red and purple urchins in this study represents the most extensive and longest such record available for nearshore species. The length of the record in both northern and southern California is sufficiently long that we should be able to detect any changes in settlement that might be associated with commercial harvesting; to date we have not. An important caveat is that the settlement record began well after the onset of the commercial fishery and none of the sites in the study are free of possible fishing effects. Our monitoring therefore lacks data before fishing began and has no un-harvested control sites. Thus, while a decreasing trend in settlement rates of red urchins would provide strong evidence of an impact of the fishery, absence of such a trend cannot rule out fairly substantial reductions settlement that may have occurred during the time between the onset of the fishery and the beginning of our study. It is worth noting, that while there are no un-harvested control sites, settlement rates of purple urchins provide a sort of control, since this species is either generally un-harvested or harvested at much lower rates than red urchins. Results of the repeated measures analyses and temporal plots show similar patterns of settlement over time for red and purple sea urchins.

To summarize, settlement patterns of both red and purple urchins have displayed peaks and valleys, but no increasing or decreasing trends in either northern or southern California over the course of our study and provides no evidence of secular declines in settlement of either species since 1990.

## TABLES

Table 1. Mean annual settlement per brush of purple (*Strongylocentrotus. purpuratus*) and red (*S. franciscanus*) sea urchins in northern and southern California. Areas are arranged from north to south: WP=Westport, PC=Point Cabrillo, PA=Point Arena, GP=Gaviota Pier, EP=Ellwood Pier, SW=Stearn's Wharf, LC=Landing Cove Pier on east Anacapa Island, SP=Scripps Institution of Oceanography Pier, OP=Ocean Beach Pier.

Mean number of purple urchin settlers per brush per year												
Year	Northern Sites			Southern Sites						Combined Means		
	WP	PC	PA	GP	EP	SW	LC	SP	OP	All	North	South
1990	0.0	0.0	0.0		4.4			39.8	5.0	8.2	0.0	16.4
1991	1.2	7.4	0.0	90.9	5.0	13.8		13.5	7.9	17.5	2.8	26.2
1992	27.2	46.1		52.8	3.5	5.8	16.3	8.4	6.4	20.8	36.7	15.5
1993	0.6	78.7		5.4	0.9	1.7	2.5	3.1	1.2	11.8	39.6	2.5
1994	2.1	15.3		36.9	7.0	29.7	101.9	33.4	47.3	34.2	8.7	42.7
1995	2.2	4.7	1.6	7.4	0.9	6.4	20.9	9.8	11.4	7.3	2.8	9.5
1996	2.7	5.4	0.7	155.3	45.3	11.9	176.0	26.1	15.7	48.8	2.9	71.7
1997	0.0	10.3	1.8	43.0	17.0	18.9	18.1	1.8	0.7	12.4	4.0	16.6
1998	4.7	21.0	1.7	2.3	2.3	4.3	3.9	0.5	0.0	4.5	9.1	2.2
1999		0.0	0.3	139.2	46.3	75.9	383.3	38.3	28.3	88.9	0.2	118.5
2000		0.0	1.1	233.5	59.3	104.7		115.2	41.1	79.3	0.6	110.7
2001		1.9	1.7	253.8	40.7	145.4		55.6	10.3	72.8	1.8	101.1
Mean	4.5	15.9	1.0	92.8	19.4	38.0	90.4	28.8	14.6			
SD	8.2	22.7	0.7	86.4	20.9	46.3	124.5	31.1	15.2			
CV %	180.1	142.9	71.5	93.1	108.1	121.8	137.8	108.1	104.1			

Mean number of red sea urchin settlers per brush per year												
Year	Northern Sites			Southern Sites						Combined Means		
	WP	PC	PA	GP	EP	SW	LC	SP	OP	All	North	South
1990	0.0	1.1	0.4		0.2			2.6	0.0	0.7	0.5	0.9
1991	0.0	0.0	0.0	14.9	2.3	2.7		1.7	0.0	2.7	0.0	4.3
1992	2.9	4.1		2.9	0.9	0.8	1.6	2.0	0.5	2.0	3.5	1.5
1993	0.0	2.7		0.1	0.0	0.1	0.0	0.1	0.0	0.4	1.4	0.1
1994	0.0	0.0		0.3	0.1	2.0	5.0	2.0	0.7	1.3	0.0	1.7
1995	0.0	0.0	0.6	0.0	0.0	0.1	0.6	1.7	0.3	0.4	0.2	0.4
1996	0.7	0.8	0.0	1.6	1.3	0.9	4.0	0.4	0.2	1.1	0.5	1.4
1997	0.0	0.5	0.0	2.5	1.9	1.0	0.0	0.2	0.0	0.7	0.2	0.9
1998	0.0	2.8	0.2	0.2	2.6	0.9	1.6	0.2	0.0	0.9	1.0	0.9
1999		0.0	0.0	0.2	2.6	1.2	0.0	0.2	0.0	0.5	0.0	0.7
2000		0.0	0.0	0.4	0.3	0.3		0.5	0.0	0.2	0.0	0.3
2001		0.0	0.0	4.4	1.0	0.8		3.1	0.5	1.4	0.0	2.0
Mean	0.4	1.0	0.1	2.5	1.1	1.0	1.6	1.2	0.2			
SD	0.9	1.4	0.2	4.2	1.0	0.7	1.8	1.0	0.3			
CV %	228.3	135.3	156.6	166.2	88.6	74.2	112.9	83.5	132.7			

Table 2. Results of repeated measures analysis of variance examining the effects for REGION (Northern vs. Southern California), YEAR, and REGION X YEAR interactions on rates of purple sea urchin (*Strongylocentrotus purpuratus*) settlement.

<u>Source</u>	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F Value</u>	<u>Prob &gt; F</u>
Year	11	1.530	0.139	1.542	0.186
Year*REGION	11	4.577	0.416	4.614	0.001
Within Subject Error	22	1.984	0.090		
REGION	1	0.083	0.083	0.371	0.604
Between Subject Error	2	0.449	0.224		

Table 3. Results of repeated measures analysis of variance examining the effects for REGION (Northern vs. Southern California), YEAR, and REGION X YEAR interactions on rates of red sea urchin (*Strongylocentrotus franciscanus*) settlement.

<u>Source</u>	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F Value</u>	<u>Prob &gt; F</u>
YEAR	11	0.0065	0.0006	1.8759	0.1008
YEAR*REGION	11	0.0073	0.0007	2.1188	0.0645
Within Subject Error	22	0.0069	0.0003		
REGION	1	0.0001	0.0001	0.0767	0.8079
Between Subject Error	2	0.0028	0.0014		